A Physical Method for a Satellite-based Surface Radiation Database

Manajit Sengupta[1], Andrew Heidinger[3], Steven Miller[2] and David Renne[1]
(1) National Renewable Energy Laboratory, 1617 Cole Blvd., Golden CO 80401, USA: Phone: +1 (303) 346-4888; Email: Manajit.Sengupta@nrel.gov
(2) Cooperative Institute for Research in the Atmosphere (CIRA), Colorado State University
(3) Center for Satellite Applications and Research (STAR), NOAA

1. ABSTRACT:

A physical based two stage algorithm for retrieving surface irradiance has been created for the GOES series of satellites but can be adapted to any other geostationary satellites measuring at visible and infrared wavelengths. As cloud properties are retrieved both Direct Normal Irradiance (DNI) and Global Horizontal Irradiance (GHI) can be directly calculated using a radiative transfer model. The goal of this research was to investigate the quality of satellite derived GHI from the GOES-11 (GOES-West) satellite for selected locations in the United States where quality ground measurements are available. The initial results, from analysis of a year (2009) of data, show that the methodology holds promise. We expect to build on this analysis and create a 10-15 year high quality surface radiation dataset which can be used by industry for site location purposes.

2. INTRODUCTION:

Addressing the challenge of solar energy availability requires a comprehensive long term analysis of multiyear surface solar radiation estimates rendered at high spatial and temporal resolution. The most straightforward method is to have well calibrated instruments such as radiometers located at the surface to take multiyear measurements but such methods are not practical on a global scale. An alternative method for obtaining long term surface solar radiation data involves retrieving surface flux from satellite measurements from geostationary satellites which offer broad spatial coverage and high temporal resolution. The current Geostationary Operational Environmental (GOES) series of satellites, operated by the National Oceanic and Atmospheric Administration, provides nominal 4 km resolution coverage of the continental United States at every half-hour [1] and has been available since 1994 thereby providing the potential to develop a long term, high temporal and spatial resolution surface radiation dataset. Once long-term GHI and DNI datasets are created and validated using high quality ground-based measurements these datasets can be used for site selection for setting up Concentrated Solar Power (CSP) and photovoltaic (PV) plants. Currently available datasets from satellites are derived using empirical and semi-empirical methods because of the speed and simplicity of those calculations. Methods created using a physical basis (referred to as the physical methods), where cloud properties are retrieved from satellite measurements and used in radiative transfer models as inputs, are generally more complicated. This paper mainly deals with validation of a physical method developed under the Global Solar Insolation Project (GSIP) at U. Wisconsin-Madison for operational use by the National Oceanic and Atmopsheric Administration (NOAA).

3. METHOD:

Empirical methods that establish relationships between satellite radiances and surface measured radiation have been widely used to retrieve surface radiation because of their speed [2]. Physical methods, on the other hand, have not been used operationally because of their inherent complexity. These physical methods involve a 2-stage process that first computes cloud properties and those properties in a radiative transfer model to compute surface radiation.

With the advent of faster processing we currently are capable of applying physical based methods at high resolution to geostationary satellites. As mentioned above the first stage of the physical method includes the physical retrieval of cloud microphysical and optical properties via a complex multi-stage algorithm that is applicable to multiple satellites. The retrieval algorithm first creates a cloud mask and cloud type using ancillary information including surface type, land-sea masking, surface elevation and monthly climatologies of Sea Surface Temperature and Normalized Vegetation Index over land. The "Clouds from AVHRR" (CLAVR) algorithm for AVHRR [3] is perhaps the most rigorously tested cloud retrieval algorithm, as it has been used operationally for multiple years. An extended version of the CLAVR algorithm, called CLAVR-x [4], has been adapted for GSIP. Full radiative transfer computations are slow and cannot be adopted for operational purposes. As such, the second stage involves a fast computation of surface radiation using the cloud information obtained from the first stage [5]. We have been running a version of the GSIP is in testing mode and results from those runs will be presented.

4. RESULTS:

The physical based GSIP algorithm has been set up to run real time for the GOES-11 satellite. Satellite data is collected from the NOAA National Environmental Satellite, Data, and Information Service (NESDIS) servers and weather model output from NOAA's Global Forecast System (GFS) is collected from the National Weather Service (NWS) servers. These two datasets are combined with ancillary information about surface type, land/sea mask, surface elevation, sea surface temperature and other climatological data to produce cloud mask, type, and properties. The cloud information serves as input to a fast radiative transfer scheme that produces surface radiation for every satellite pixel in the scene (e.g. Figure 1d). In these runs the cloud properties are retrieved every half-hour at a nominal resolution of 4 km to match the spatial resolution of the infrared channel on the GOES-Imager. The surface radiation, though, is computed at $1/8^{o}$ resolution and includes information from approximately a grid of 3X3 satellite pixels for which the cloud properties have been retrieved.

Surface based measurements provide an excellent tool for validation of the satellite based algorithm. We therefore selected sites located at Desert Rock, NV and Hanford, CA as well calibrated GHI measurements are available every minute from those sites. While Desert Rock, NV is a NOAA Surface Radiation (SURFRAD) network site Hanford, CA is n Integrated Surface Irradiance Study (ISIS) network site. For our comparisons with the satellite retrievals surface GHI was averaged from 5 minutes to 2 hours centered on the satellite measurement. As previously mentioned the satellite retrievals are available every 30 minutes. These satellite retrievals are instantaneous snapshots but represent average surface radiation for areas equal to the pixel size. To represent the finite spatial extent of satellite pixels we averaged the ground based data to different time periods under the assumption that temporal averaging of instantaneous surface data can reasonable represent larger spatial dimensions. The goal was to understand the impact of different timescales used to create the spatially averaged data. This is especially important as there are satellite based surface radiation products that represent hourly averages of surface radiation. Correlations , Mean Bias Error (MBE) and Root Mean Square Error (RMSE) were calculated. Monthly (not shown) and annual comparisons were made for different cloud scenes classified as (a) overcast, (b) partly clear, (c) partly cloudy and (d) clear to represent decreasing cloudiness derived from cloud fraction values. The results of the annual comparisons are shown in Figure 2 and 3 and Table 1. The GHI correlations from all the sites shows that the satellite derived values are well correlated with the surface observations with correlations around 0.95. As expected the clear sky periods have the highest correlation of 0.99. It is observed that the retrievals are slightly better correlated with a lower root mean square error for surface data averaged over larger time intervals (60 minutes or more) as seen in Figure 3. Those cases with high cloud cover have higher RMSE and and lower correlations. Biases in cases of high cloud cover are also higher as seen in Figure 3.

5. CONCLUSIONS AND FUTURE WORK:

A physical based two stage algorithm for retrieving surface irradiance has been created for the GOES series of satellites but is useful for any other geostationary series of satellites. The goal of this research was to investigate the quality of the surface flux derived from GOES data using a physical method for selected locations in the United States. The desert southwest region is of particular interest to solar utility developers because of the low climatological occurrence of clouds in this region. A validation of the quality of the datasets being produced is necessary to build confidence in the user community. The retrievals were verified using surface based measurements from Desert Rock, Nevada and Hanford, California and the results shown in Figure 2 indicated that the retrievals are realistic and useful.

Future plans include 1) gathering sufficient surface radiation datasets for different sites in the U.S. to validate the GSIP results, and 2) set the stage for a comparative study of the quality of the data being produced via GSIP and those using various empirical methodologies[6]. We expect to build on this analysis and create a 10-15 year high quality surface radiation dataset which can be used by industry for site location purposes. In addition to the retrospective work proposed here, we plan to examine the skill of surface solar radiation forecasts based on realistic regional-scale models (including explicit cloud microphysics) for the purpose of predicting future power availability. The latter is of keen interest to industry, and can be validated through the satellite tools being developed for this phase of the work.

REFERENCES:

[1] Weinreb, M. P., M. Jamison, N. Fulton, Y. Chen, J. X. Johnson, J. Bremer, C. Smith, and J. Baucom, 1997: Operational calibration of Geostationary Operational Environmental Satellite-8 and -9 imagers and sounders. *Appl. Opt.,* **36,** 6895–6904.

[2] Perez, R., P. Ineichen, K. Moore, M. Kmiecik, C. Chain, R. George, F. Vignola, 2002: A new operational model for satellite-derived irradiances: description and validation. *Solar Energy*, **73,** 307-393.

[3] Stowe, L. L., P. A. Davis, and E. P. McClain, 1999: Scientific basis and initial evaluation of the CLAVR-1 global clear cloud classification algorithm for the Advanced Very High Resolution Radiometer. *J. Atmos. Oceanic Technol.,* **16,** 656–681.

[4] Heidinger, A. K., 2003: Rapid daytime estimation of cloud properties over a large area from radiance distributions. *J. Atm. Oceanic Tech.,* **20,** 1237-1250.

[5] Lazlo, I., P. Ciren, H. Liu, S. Kondragunta , J. D. Tarpley , M. D. Goldberg, 2008: Remote sensing of aerosol and radiation from geostationary satellites. *Adv. Space Res.*, **41**, 1882–1893.

[6] Sengupta, M., E. E. Clothiaux and T. P. Ackerman, 2004: Climatology of Warm Boundary Layer Clouds at the ARM SGP Site and Their Comparison to Models. J. Clim., **17**, 4760-4782.

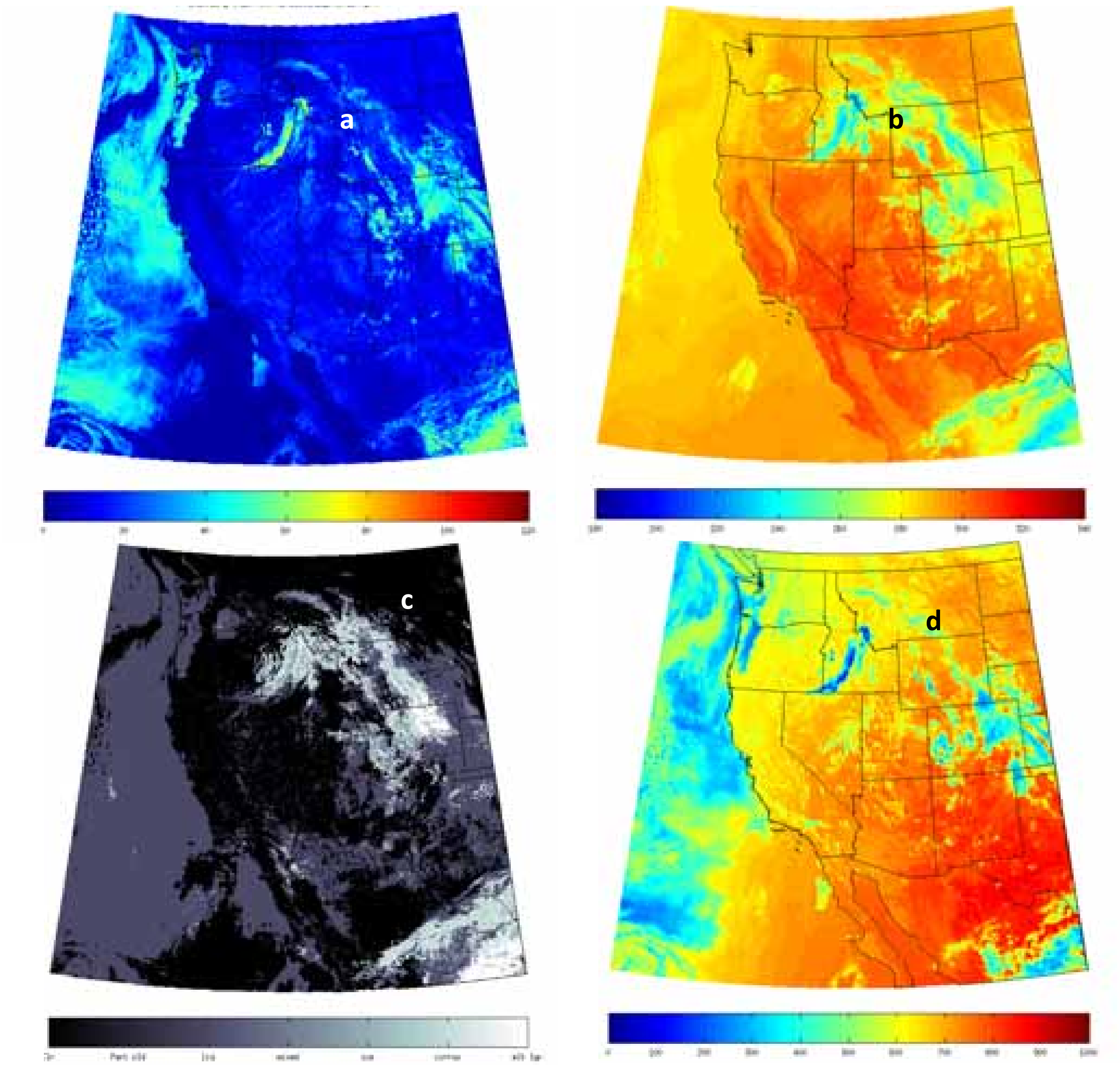

Figure 1. Visible reflectance (1(a)) and infrared brightness temperature (1(b)) from GOES 11 and the corresponding cloud (1(c)) and surface radiation (1(d)) retrievals for August 30, 2009 at 1700 UTC are shown in this figure. The cloud properties from 1(c) are used to create the GHI in 1(d).

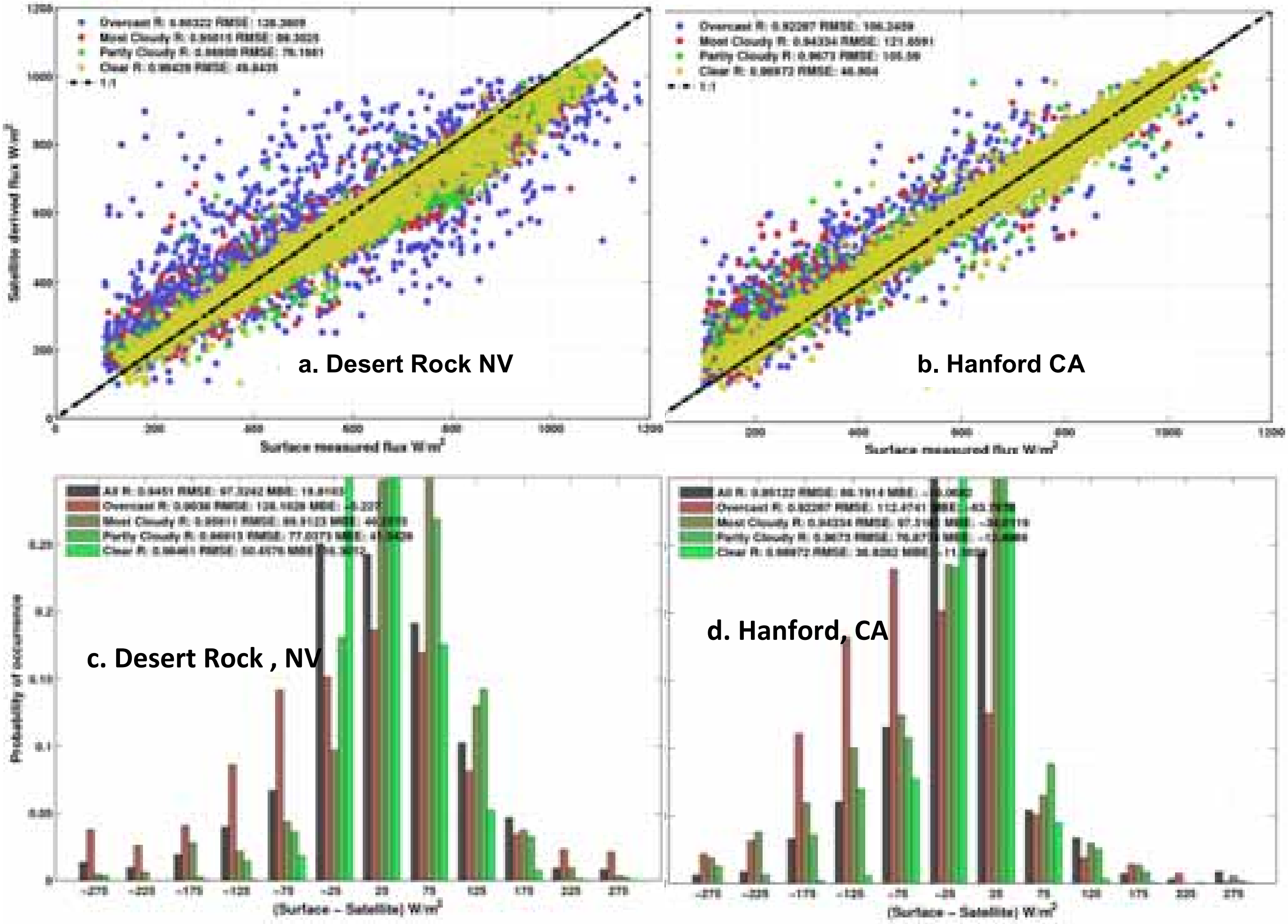

Figure 2. Comparison of Global Horizontal Irradiance measured at (a & c) Desert Rock, NV and (b&d) Hanford, with retrievals from the GOES-11 satellite for 2009.As expected the clear sky comparisons have lower bias and error than broken and overcast cloud situations.

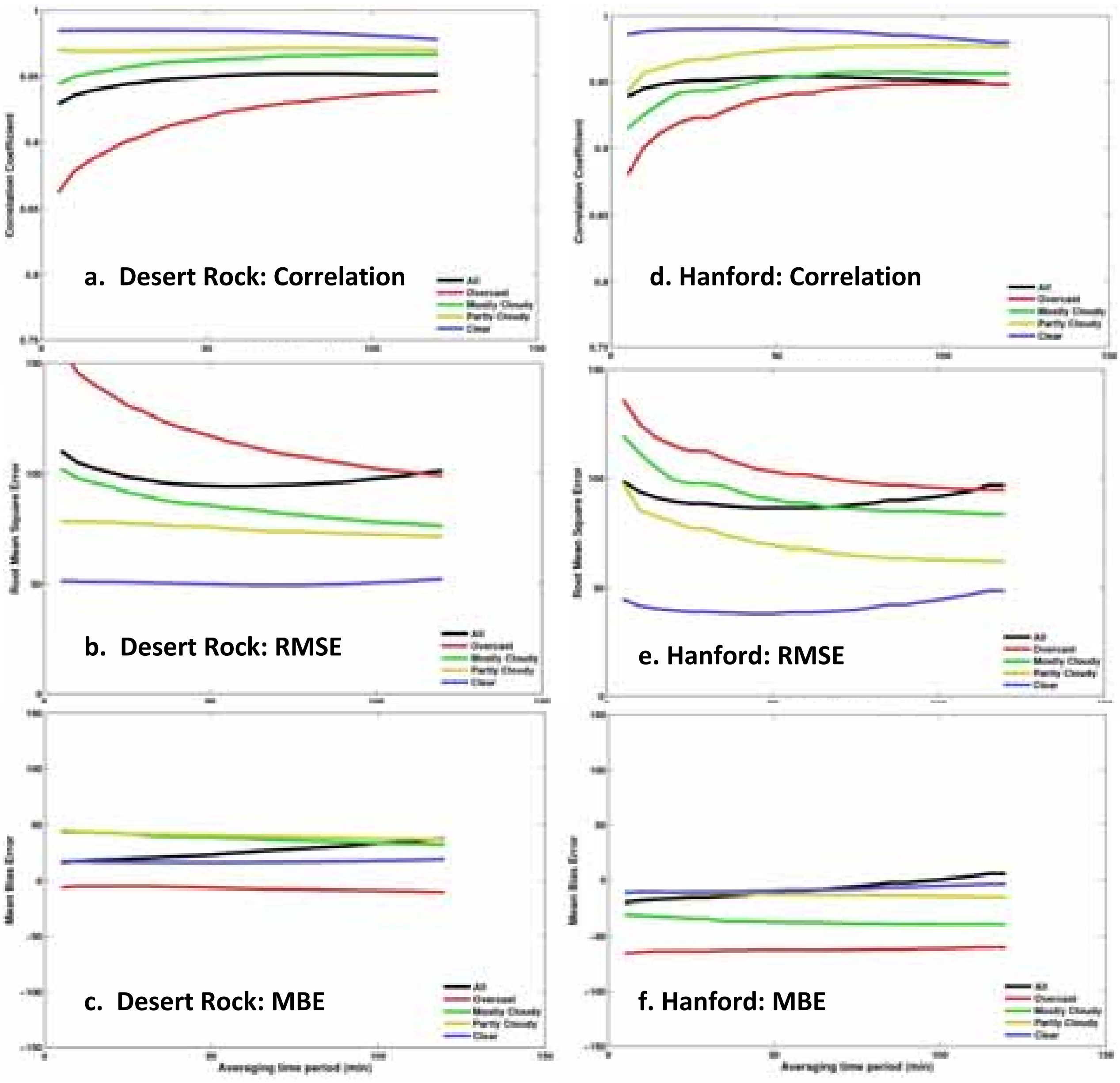

Figure 3.Statistics of the comparison of Global Horizontal Irradiance measured at (a,b &c) Desert Rock, NV and (d,e & f) Hanford, with retrievals from the GOES-11 satellite for 2009. The ground measurements are averaged from 5 minutes to 120 minutes centered on the satellite observations. Note that averaging progressively reduces MBE and RMSE.

Table 1: This table shows the correlation (R), Root Mean Square Error (RMSE) (W/m^2) and Mean Bias Error (MBE) (W/m^2) for comparisons between satellite derive surface GHI and measured GHI averaged to 30 minutes and 60 minutes. 1 year of data (2009) was used for this comparison where clear, partly cloudy, partly clear and overcast represent the quartiles that progressively represent cloud cover.

Data Type		**Desert Rock, NV**		**Hanford, CA**	
		30 min avg	**60 min avg**	**30 min avg**	**60 min avg**
All	**R**	0.95	0.95	0.95	0.95
	RMSE	97.32	94.14	88	86.22
	MBE	19.81	25.01	-16.07	-10.06
Overcast	**R**	0.90	0.92	0.92	0.94
	RMSE	128	112.87	112.47	101.76
	MBE	-5.23	-7.41	-63.80	-62.83
Partly Clear	**R**	0.96	0.96	0.94	0.96
	RMSE	89.9	83.74	97.52	88.57
	MBE	40.26	37.75	-34.01	-37.41
Partly Cloudy	**R**	0.97	0.97	0.97	0.98
	RMSE	77.03	74.55	76.88	67.75
	MBE	41.54	39.95	-12.50	-13.55
Clear	**R**	0.99	0.98	0.99	0.99
	RMSE	50.46	49.37	38.93	38.62
	MBE	16.30	16.09	-11.10	-9.39